Wake Region Perturbation for Base Drag Reduction

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INTRODUCTION. Small and medium caliber tracer ammunition has served in the role of providing fire control capability to modern rapid-fire weapons. In addition to this role, tracers have also been shown to have a decided psychological effect both on the enemy (a negative effect of spreading fear and chaos throughout his ranks) and on the gunner (a positive effect indicative of his effective firepower). Ancillary to these roles, tracers have been performing in a generally overlooked capacity, that of projectile base drag reduction. How tracers have performed in this role is illustrated by differences in performance observed between the 7.62mm (M62) tracer round and the 7.62mm (M80) ball round. In flight, the tracer projectile clearly experiences a lower overall drag force and therefore has a higher downrange velocity. Until recently, this difference was viewed only as a problem in ballistic mismatch between ball and tracer rounds, and was not recognized as an opportunity for providing superior velocity retention characteristics (drag reduction) to all rounds. Recent work[1], however, has demonstrated that elimination of the "base drag" component of the drag force acting on a projectile in flight would result in significant downrange velocity increases. In practice, projectile base drag can be reduced by carefully controlling the mass and heat transfer of gas into the projectile base region during flight.[2] This reduction process has been given the term "fumer" effect, and projectiles employing the effect are referred to as fumer projectiles, or simply "fumers".

Results of an early study on base drag reduction of projectiles by gas ejection indicate that the pressure at the projectile base (due to gas ejection) is a function of the flow rate,

composition and temperature of ejected gas, the Mach number, boundary layer thickness, afterbody geometry and the method of gas ejection[3]. Efficiency of the gas ejection process was found to increase under the following conditions: hot gas, low gas ejection velocity, and low gas molecular weight. As a result of these previous studies, and based upon potential gains which their results promised, a program was initiated at Frankford Arsenal, with the objectives of better understanding the basic parameters controlling the fumer effects, as well as developing practical small and medium caliber fumer cartridges and assessing the magnitude of drag reduction obtained. Reports on the progress of this work to date have indicated that, with present-day technologies, striking energies of projectiles can be more than doubled without modification to the weapon or propulsion systems.[4-6] This paper relates significant results of that effort, and presents new data on the influence of base pressure on the trajectory of specific caliber ammunition.

BASE DRAG STUDIES. A pyrotechnic approach to providing base drag reduction for small and medium caliber projectiles was chosen as the most likely path to succeed. This decision was based upon the availability of considerable knowledge and expertise in pyrotechnic tracer technology, as well as upon the promising performance already obtained with tracer projectiles. Integral to this approach was the laboratory screening of candidate pyrotechnic materials for fumer application. This approach is described in Reference 4, but will be briefly explained for the sake of continuity. Pyrotechnic personnel selected four criteria for the evaluation of potential fumer mixes: heat of reaction, adiabatic-flame temperature, linear-burning rate and combustion products. Using a spinning fixture, ignition and linear-burning data were determined for promising fumer mixes at 40,000 revolutions per minute. Continuous screening of potential fumer compositions included modified tracer materials as well as stoichiometric fuel-oxidizer compositions. Emphasis was placed on stoichiometric mixes since the stiochiometric flame is most efficient in the near wake (partial vacuum) region.

Potential fumer composition selections were formulated to qualitatively determine which emission characteristics significantly influenced base-drag reduction. The spectrum of compositions selected for this investigation displayed combustion characteristics depicted on the heat/mass output matrix below.

HEAT/MASS OUTPUT MATRIX

Heat Heat High Mass	High Heat Low Mass
Low Heat High Mass	Low Heat High Mass

Utilizing the 7.62mm M62 tracer projectile as the test vehicle, several promising fumer materials, along with the standard tracer mix, R-284, and an inert mix were Doppler-radar tested at the Frankford Arsenal Experimental Range at Fort Dix for drag-reduction evaluation. Two compositions, Fumer 4 and R284, exhibited significantly superior drag-reducing characteristics over the inert mixture. R284 is Magnesium/Strontium Nitrate/Polyvinylchloride, while Fumer 4 is Magnesium/Strontium Nitrate/Calcium resinate. Both compositions, also exhibited high heat/medium mass output. Similar good results were obtained in applying these and other compositions to the 20mm family of ammunition. In addition to the laboratory screening of compositions for fumer application and the projectile flight tests utilizing Doppler-effect radar, other investigations, primarily analytical, were conducted to further the understanding of base-drag reduction via gas generators. These efforts included wind-tunnel testing of various materials and in-flight projectile laser-holography studies. The wind-tunnel tests are designed to increase our understanding of the flow pattern and actual base pressure of different mixes at various mach numbers.[8]

The laser-holography experiments have given the first in-flight pictorial representation, utilizing this technique, of the shock-wave pattern resulting from the projectile charged with a fumer composition. When the laser interferogram of a 7.62mm M62 inert filled projectile is compared with that of a similar projectile charged with Fumer 4, it is noteworthy that the trailing shocks and wake region of the two projectiles differ vastly.

Relative to the 7.62mm work, the best fumer compositions were found to reduce overall drag of the M62 projectile by more than 30 percent at selected Mach numbers. Kinetic-energy increases (as high as 70 percent) were attained with certain fumer mixtures (over inert-filled, control projectiles). In general, the employment of fumers was found to be most beneficial in projectiles having high base-drag components.

BASE PRESSURE EFFECT ON TRAJECTORY. A series of calculations was conducted to determine the effect of base pressure on the trajectory of a 20mm, 120-gram projectile. For the purpose of this analysis, it was assumed that all other contributions to overall projectile drag remained constant while base drag changed. This is a reasonable assumption if the projectile nose configuration remains fixed.

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Base drag coefficients for cylindrical afterbodies are available in the literature. Base pressures can be computed from this information using the relationship

$$P_b = P_a - Cq, \qquad (1)$$

where

P_b = base pressure

P_a = atmospheric pressure

C = base drag coefficient

q = dynamic pressure

Base pressures were calculated over the range from Mach 0.5 to Mach 3.5, and the results obtained were fed into formulae describing the trajectory,

$$P_{bI} = P_b + (P_a - P_b)/2, \qquad (2)$$

and

$$x = f(t,v)$$
$$y = g(t,v) \qquad (3)$$

where equations 3 describe a differential equation for position (x horizontal or y vertical) in terms of elapsed time, t, from the muzzle and velocity, v. Reductions in time of flight are listed below for selected ranges:

	RANGE, METERS		
TIME OF FLIGHT	/ 1000	2000	3000
REDUCTION, SECONDS:	0.04	0.15	0.44

The time-of-flight reduction is more evident at longer ranges, being relatively small up to 2,000 meters. Velocity increases are, however, considerably higher, as is shown in the following table:

	TIME OF FLIGHT, SECONDS		
	/1.2	2.4	3.6
VELOCITY INCREASE, (M/SEC)	110	181	240

The striking energy of fumer projectiles is considerably higher than that for a non-fumer (inert) projectile:[7]

	DISTANCE, METERS		
	/ 1000	2000	3000
ENERGY INCREASE (NEWTON METERS)	10,400	19,000	25,600

These results indicate that fumers have a high potential for increasing the striking kinetic energy of projectiles, and it would be quite reasonable to employ fumers for conditions where penetration performance is marginal. Further calculations show that the effect of decreasing fumer composition mass (total projectile weight varies from 120 grams at the muzzle to approximately 115 grams at fumer burnout) on overall projectile deceleration behavior is relatively small. Still further calculations were made on characteristics of the fumer gas products. Results show that fumers emitting gases with a high molecular weight are impractical. The most desirable combination of properties is a gas having a low molecular weight and a composition with a high flame temperature.

SUMMARY. Fumer technology promises most beneficial results in terms of imparting terminal effects characteristics to selected ammunition. Fumers should not be employed, however, strictly to reduce time of flight. Fumer projectiles at a selected range do have considerably higher striking energy, and should therefore be considered for use where marginal penetration performances is expected. An optimized fumer round would ideally have some degree of programmed burning of the pyrotechnic composition inherent in its design. A good fumer must produce low molecular weight gases at very high temperatures. Generally speaking, the use of fumers makes sense if the projectile in question is optimized with respect to its contour (low drag shape). A practical compromise would appear to be a ballistically sound projectile having an optimized contour (low drag shape) and a tracer element which serves both as a fire control aid (bright tracer) and as a fumer.
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